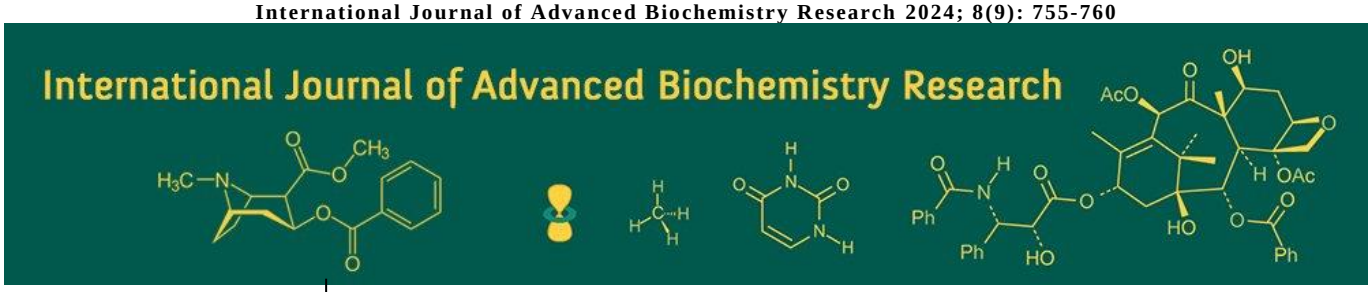


**ISSN Print:** 2617-4693
**ISSN Online:** 2617-4707
IJABR 2024; 8(9): 755-760
www.biochemjournal.com
Received: 15-06-2024
Accepted: 18-07-2024

**G Manisankar**
Ph.D. Research Scholar, Department of Agronomy, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, West Bengal, India

**GC Malik**
Professor and Head, Department of Agronomy, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, West Bengal, India

**M Banerjee**
Associate Professor, Department of Agronomy, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, West Bengal, India

**P Ghosh**
Assistant Professor, Department of Agronomy, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, West Bengal, India

**Corresponding Author:**
**GC Malik**
Professor and Head, Department of Agronomy, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, West Bengal, India

# Metsulfuron methyl: A versatile low dose and high efficiency herbicide for optimal weed management in transplanted rice

**G Manisankar, GC Malik, M Banerjee and P Ghosh**

**DOI:** https://doi.org/10.33545/26174693.2024.v8.i9j.2264

**Abstract**
A field study was conducted at the Agricultural Farm, Institute of Agriculture, Visva-Bharati, West Bengal, during the monsoon season 2023 (*kharif*) to explore the effect of metsulfuron methyl on optimized weed management in transplanted rice. The experiment was carried out using a randomized block design (RBD) with eleven treatments, which were replicated thrice. The treatments included, four different doses of encapsulated and commercial metsulfuron methyl viz., 2 g a.i $ha^{-1}$, 3 g a.i $ha^{-1}$, 4 g a.i $ha^{-1}$ and 5 g a.i $ha^{-1}$. These treatments were compared with the farmers practice of hand weeding twice at 20 and 40 days after transplanting. The weed free check and unweeded control treatments were maintained for evaluating the weed control efficiency of commercial and encapsulated metsulfuron methyl. Both commercial and encapsulated formulations of metsulfuron methyl were applied as pre emergence on five days after transplanting and the solvent evaporation method was utilized for encapsulating metsulfuron methyl. The findings revealed that, among the herbicidal treatments, pre emergence application of encapsulated metsulfuron methyl at 5 g a.i $ha^{-1}$ resulted in lower weed density (16.00 $m^{-2}$), reduced weed dry weight (3.99 g $m^{-2}$), greater weed control efficiency (97.27%), higher weed control index (97.35%), maximum grain yield (5816 kg $ha^{-1}$) and a modest weed index (2.44%) compared to others. However, this was closely followed and statistically at par with encapsulated metsulfuron methyl 4 g a.i $ha^{-1}$. Notably, the application of encapsulated metsulfuron methyl at 2 g a.i $ha^{-1}$ resulted significantly lower weed density (41.33 $m^{-2}$), reduced weed dry weight (10.99 g $m^{-2}$), superior weed control efficiency (92.95%), enhanced weed control index (92.70%), substantial grain yield (5257 kg $ha^{-1}$) and a reduced weed index (11.81%) than recommended dose of commercial metsulfuron methyl 4 g a.i $ha^{-1}$. Considering the ecological balance, environmental sustainability and shortage of skilled agriculture labour, this study concludes that, pre emergence application of encapsulated metsulfuron methyl at 2 g a.i $ha^{-1}$ on five days after transplanting is ideal for effective weed control, enhanced productivity and profitability of transplanted rice.

**Keywords:** Encapsulation, herbicide, metsulfuron methyl, solvent evaporation, transplanted rice, weed management

## Introduction
Rice (*Oryza sativa* L.) holds a significant position in global agriculture and serving as the primary staple food for over 60% of the world's population. Compared to other crops, rice is the sole food consumed by more people worldwide. Globally, rice cultivation spans 165.04 million hectares, annually producing approximately 517.34 million tonnes with an average productivity of 3.13 tonnes per hectare (USDA, 2024) [16]. Rice is cultivated in more than a hundred countries, with the top ten rice producers being China (28%), India (26%), Bangladesh (7%), Indonesia (6%), Vietnam (5%), Thailand (4%), Philippines (2%), Burma (2%), Pakistan (2%) and Japan (1%). Rice production increased more than threefold after the introduction of high-yielding varieties during the green revolution.

Despite its paramount importance, rice cultivation faces significant challenges from weed infestations, particularly in distinct wetland ecosystems where weeds can emerge rapidly after transplanting. They compete vigorously with rice during critical growth stages, leading to a reduction in grain yield (Thura, 2010) [15]. The weed infestation in transplanted rice can result in yield reductions ranging from 27% to 68% (Yadav *et al.*, 2018) [18].

Chemical weed management remains essential in mitigating these challenges, particularly in regions experiencing shortages of skilled agricultural labour (Sureshkumar *et al.*, 2016) [14].

However, concerns over environmental impact and food safety have prompted advancements in herbicide technologies. In this context, nanoherbicides offer improved weed management compared to commercial herbicides due to their extended persistence and slow release mechanism in soil at lower doses.

The encapsulation approach has been identified as an efficient and precise methods for nanoherbicide formulation (Sahoo *et al.*, 2022 and Vikram, 2020) [11, 17]. This technique involves coating the herbicide with a hydrophilic polymer to create a protective barrier that releases the herbicide upon contact with moisture. This controlled release mechanism ensures sustained weed control throughout the growing season.

Currently, the low dose herbicides such as bensulfuron methyl 60% DF (60 g a.i/100 g formulation $ha^{-1}$), bispyribac sodium 10% SC (20 g a.i/200 g formulation $ha^{-1}$), chlorimuron ethyl 25% WP (6 g a.i/24 g formulation $ha^{-1}$), metsulfuron methyl 20% WP (4 g a.i/20 g formulation $ha^{-1}$) and pyrazosulfuron ethyl 10% WP (10 g a.i/100 g formulation $ha^{-1}$) are available in the market for effective weed management in transplanted rice. Among these herbicides, metsulfuron methyl exhibits outstanding broad spectrum weed control efficiency and can effectively manage various weeds such as *Digitaria sanguinalis* in grasses, *Cyperus esculentus*, *Cyperus rotundus* and *Fimbristylis species* in sedges, *Amaranthus viridis*, *Anagallis arvensis*, *Chenopodium album*, *Cleome viscosa*, *Commelina benghalensis*, *Cirsium arvense*, *Euphorbia species*, *Ludwigia parviflora*, *Lathyrus aphaca*, *Marsilea quadrifoliata*, *Parthenium hysterophorus*, *Portulaca oleracea*, *Solanum species*, *Spheanocheila species*, *Trianthema species* and *Vicia sativa* in broad leaved weeds. Metsulfuron methyl notably expands its capacity to control 20 weeds across diverse cropping systems, surpassing other listed low dose herbicides.

Metsulfuron methyl effectively controls weeds by inhibiting the enzyme acetohydroxyacid synthase (AHAS), a vital component in the branched chain biosynthesis of amino acids such as valine, leucine and isoleucine (Sumekar *et al.*, 2021) [13]. Its mode of action involves inhibiting cell division in both shoots and roots of the plant. Metsulfuron methyl demonstrates biologically active properties even at low application rates and proves particularly effective against weeds that possess bulbs and tubers. Moreover, it exhibits good rain fastness even after four hours of application and due to a systemic herbicide with contact and residual action, providing long-lasting control by remaining active in the soil to prevent new weed emergence. Notably, metsulfuron methyl affects perennial weeds by gradually weakening their root systems over time.

Due to these attributes, metsulfuron methyl has garnered increased attention for its efficacy in weed control and its versatile application timings. Metsulfuron is often paired with chlorimuron ethyl under the trade name Almix, widely favoured for its effectiveness at low doses. Previous findings demonstrate that, metsulfuron alone has the ability to comprehensively manage a variety of weeds, including annual grasses, sedges and broad leaved species (Kaur *et al.*, 2017) [4]. However, the longevity of metsulfuron methyl in soil remains uncertain, with a reported half-life of 6.3 to 7.9 days in acidic soil (Maznah *et al.*, 2020) [8]. Hence, improving its soil persistence, potentially through polymeric encapsulation, is crucial for sustaining its weed control efficacy beyond the critical period of crop weed competition.

Despite its efficiency at low application rates, concerns persist regarding its effectiveness in rice weed management. However, there is a notable gap in comprehensive research addressing these concerns. Recognizing these challenges, a study was initiated to explore the potential of metsulfuron methyl for optimized weed management in transplanted rice.

## Materials and Methods

A field experiment was conducted at the Agricultural Farm, Institute of Agriculture, Visva-Bharati, West Bengal, during the *kharif* season of 2023 to assess the efficiency of metsulfuron methyl for optimized weed management in transplanted rice. The experimental site was positioned at geographic coordinates 23° 40' N latitude and 87° 39' E longitude with an average elevation of 76.2 meters above mean sea level.

The study was conducted using a randomized block design with eleven treatments and was replicated thrice. The treatments included, four different doses of encapsulated and commercial metsulfuron methyl viz., 2 g a.i $ha^{-1}$, 3 g a.i $ha^{-1}$, 4 g a.i $ha^{-1}$ and 5 g a.i $ha^{-1}$. These treatments were compared with the farmer's traditional weed management practice of manual weeding twice at 20 and 40 days after transplanting (DAT). Furthermore, weed free check and unweeded control treatments were maintained to evaluate the weed control efficiency of commercial and encapsulated metsulfuron methyl. The commercial and encapsulated forms of metsulfuron methyl were applied as pre emergence. The popular rice variety MTU 7029 (Swarna) was used in this experiment with standard agronomic practices and plant protection measures.

The commercial metsulfuron methyl was purchased from katyayani organics, Madhya Pradesh, India. The encapsulated metsulfuron methyl was prepared using solvent evaporation method, employing two oppositely charged hydrophilic polymers namely, poly allylamine hydrochloride and poly sodium styrene sulfonate. The dosage for the commercial herbicide is determined by its active ingredient and formulation, while the dosage for the encapsulated form is calculated based on its encapsulation efficiency. Subsequently, each herbicide doses were mixed individually with 500 liters of water and uniformly sprayed using a knapsack sprayer equipped with a deflector nozzle.

The weed flora, weed density, weed dry weight, weed control efficiency, weed control index, grain yield, weed index were duly observed and calculated during the experimentation. The weed density and weed dry weight data were subjected to square root ($\sqrt{X} + 0.5$) transformation before statistical analysis to normalize their distribution. Weed control efficiency was calculated using the weed density data according to the formula recommended by Mani *et al.* (1973) [6] and the weed control index was calculated based on weed dry matter using the formula suggested by Misra and Tosh (1979) [9]. The degree of yield reduction caused by weeds was determined using the procedures given by Gill and Vijayakumar (1969) [2].

The data obtained from different parameters underwent statistical analysis using the analysis of variance technique suggested by Gomez and Gomez (1984) [3] for a randomized block design. When statistical significance was observed, a critical difference (CD) at the 0.05 significance level was calculated for comparative analysis. The tabular data

comprises standard error of the mean (SEm ±) and critical difference (CD) values to facilitate the comparison of differences among treatment means.

## Results and Discussion

### A. Weed flora

Evaluating weed diversity in the experimental area is crucial for implementing effective weed control measures. During land preparation, the field was found to be infested with a diverse range of weed flora, including grasses, sedges and broad leaved weeds. Among the grasses, *Digitaria sanguinalis* and *Leersia hexandra* were prevalent, *Cyperus iria* was common among the sedges and *Sphenoclea zeylanica* was notable among the broad leaved weeds. Among the observed weeds, *Leersia hexandra* was found to be a dominant, accounting for 67.67% infestation, followed by *Digitaria sanguinalis* (22.11%), *Cyperus iria* (8.87%) and *Sphenoclea zeylanica* (1.35%) (Fig. 1).

During the experimentation, the observed weed flora was *Leersia hexandra* among the grasses, *Cyperus difformis*, *Cyperus iria* and *Fimbristylis miliacea* among the sedges, *Ludwigia parviflora*, *Monochoria vaginalis* and *Sphenoclea zeylanica* among the broad leaved weeds. A similar weed flora composition was noticed by Shivashenkaramurthy *et al.* (2021) [12].

During the critical period of crop weed competition at 40 days after transplanting (DAT), broad leaved weeds were found to be the dominant category (52.96%), followed by grasses (23.86%) and sedges (23.18%). In context with weed species, *Sphenoclea zeylanica* was the most dominant weed (30.68%), followed by *Leersia hexandra* (23.86%), *Monochoria vaginalis* (20.68%), *Cyperus iria* (11.59%), *Cyperus difformis* (11.59%) and *Ludwigia parviflora* (1.59%) (Fig. 2).

The shifts in weed dominance from grasses > sedges > broad leaved weeds during land preparation to broad leaved weeds > grasses > sedges during the critical period of crop weed competition, underscores how specific adaptations and competitive strategies influence weed community dynamics over the crop growth cycle. This shift highlights the importance of understanding weed biology and ecology for effectively managing weed populations in agricultural systems. The greater leaf area of broad leaved weeds and rapid germination of grasses through their extensive rhizome networks likely contribute to this shift in weed dominance over sedges.

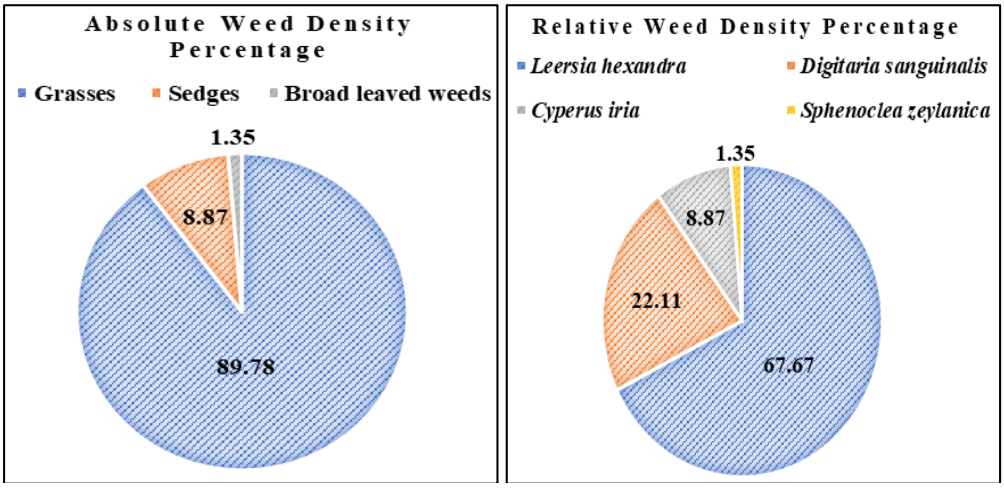


**Fig 1:** Percentage of absolute and relative weed density during land preparation.

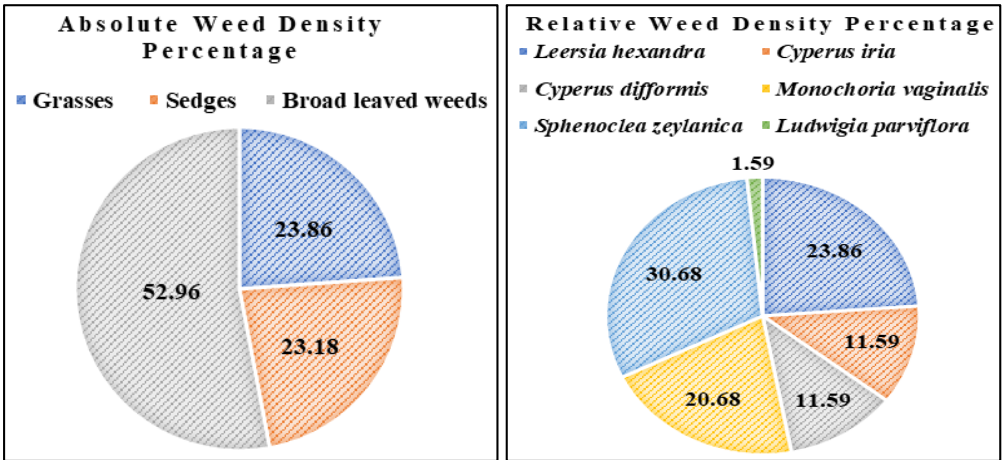


**Fig 2:** Percentage of absolute and relative weed density at 40 days after transplanting.

### B. Weed indices

Pre emergence application of encapsulated and commercial metsulfuron methyl significantly altered the weed density, weed dry weight, weed control efficiency and weed control index in transplanted rice (Table 1). Among the different treatments, weed free check and hand weeding twice at 20 and 40 DAT obtained higher weed control efficiency (100%) and enhanced weed control index (100 %) than all other treatments at 40 DAT. Consistent removal of weeds from weed free check and hand weeding at 20 and 40 days

after transplanting substantially reduced the weed density and biomass, thereby increasing the weed control efficacy and weed control index. Among the various treatments of metsulfuron methyl, pre emergence application of encapsulated metsulfuron methyl at 5 g a.i $ha^{-1}$ resulted in reduced weed density (16.00 $m^{-2}$), lower weed dry weight (3.99 g $m^{-2}$), superior weed control efficiency (97.27%) and elevated weed control index (97.35%) compared to rest of the treatments. However, this was at par with encapsulated metsulfuron methyl 4 g a.i $ha^{-1}$. Pre emergence application of commercial metsulfuron methyl 5 g a.i $ha^{-1}$ observed lower weed density (90.67 $m^{-2}$), reduced weed dry weight (32.91 g $m^{-2}$), greater weed control efficiency (84.55%) and enhanced weed control index (78.15%) than other doses of commercial metsulfuron methyl. However, these results were comparable with commercial metsulfuron methyl 4 g a.i $ha^{-1}$ and 3 g a.i $ha^{-1}$. The pre emergence application of both commercial and encapsulated metsulfuron methyl effectively controlled a wide range of weed species by inhibiting the enzyme acetohydroxyacid synthase (AHAS), crucial for the biosynthesis of amino acids valine, leucine and isoleucine. The superior performance of encapsulated metsulfuron methyl in weed management can be attributed to its advanced formulation with small particle size and high specific surface area. These characteristics allow for better soil coverage and deeper penetration to effectively targeting weed seeds and weeds via their roots, thereby resulting in significantly reduced weed density, lower weed dry weight, higher weed control efficiency and elevated weed control index than other treatments. Due to the larger particle size, limited soil penetration and faster degradation of commercial metsulfuron methyl, it probably exhibited lower efficacy than the encapsulated form. Moreover, it remains effective for controlling weeds in transplanted rice particularly at higher application rates. These results were in accordance with the findings of Mukherjee and Singh (2004) [10], who observed improved weed control efficacy in transplanted rice with pre emergence application of metsulfuron methyl at 4 g a.i $ha^{-1}$. Notably, application of encapsulated metsulfuron methyl 2 g a.i $ha^{-1}$ recorded 9.54% higher weed control efficiency and 17.63% enhanced weed control index than recommended dose of commercial metsulfuron methyl 4 g a.i $ha^{-1}$. Significantly higher weed density (586.67 $m^{-2}$) and weed dry weight (150.57 g $m^{-2}$) were obtained with unweeded control. The absence of weed management in unweeded control, allowing unrestricted weed growth and biomass accumulation, resulted in inferior weed control efficacy compared to other treatments.

**C. Grain yield and weed index**

Grain yield and weed index of transplanted rice was significantly influenced by different weed management practices (Table 1). Among the treatments, weed free check recorded higher grain yield of 5961 kg $ha^{-1}$ than other treatments. However, this was at par with hand weeding twice on 20 and 40 DAT and all other treatments of encapsulated metsulfuron methyl.

Weed free check provides ideal growing conditions by completely eliminating weed competition, thus allowing the rice plants to utilize nutrients, water and light optimally. Moreover, weed free check serves as a benchmark for obtaining potential maximum yield in the absence of crop-weed competition and highlights the importance of effective weed management for achieving optimal grain yield in transplanted rice.

The effectiveness of hand weeding can be attributed to the physical removal of weeds, which prevents competition for nutrients, light and space, thus supporting higher grain yield. Despite being labour intensive, this method proves to be a viable option for achieving substantial weed control and high grain yield.

Among the different doses of encapsulated metsulfuron methyl, 5 g a.i $ha^{-1}$ achieved maximum grain yield (5816 kg $ha^{-1}$) than other doses. Similarly, in context with commercial metsulfuron methyl, 5 g a.i $ha^{-1}$ registered notably better grain yield (4721 kg $ha^{-1}$) than others. This was closely followed and statistically at par with all other treatments of commercial metsulfuron methyl.

The slow-release mechanism of encapsulated metsulfuron methyl ensures a controlled and prolonged release of the active ingredient, providing sustained weed suppression throughout the growing season, which allows the crop to thrive without competition and ultimately results in increased yield.

Commercial metsulfuron methyl achieved lower grain yield and higher weed index than the weed free check, hand weeding twice and encapsulated metsulfuron methyl due to its variations in herbicidal activity and potentiality to manage weeds resulting in marginal weed control and allowing few weed species to persist and compete with rice plants. This compromised weed control efficacy ultimately leads to lower grain yield compared to the more precise and sustained weed management achieved by other treatments. The enhanced stability, solubility and bioactivity of encapsulated herbicides resulted in better weed control efficiency and higher yields compared to traditional commercial herbicides (Marimuthu *et al.*, 2022) [7].

In terms of weed index, pre emergence application of encapsulated metsulfuron methyl 5 g a.i $ha^{-1}$ obtained the lower weed index (2.44%) than other treatments. However, this was at par with encapsulated metsulfuron methyl 4 g a.i $ha^{-1}$. Hand weeding twice on 20 and 40 DAT recorded the weed index of 8.81% and this was at par with encapsulated metsulfuron methyl 3 g a.i $ha^{-1}$ and 2 g a.i $ha^{-1}$. Among the commercial metsulfuron methyl, 5 g a.i $ha^{-1}$ noticed noteworthy weed control index (20.80%) than other doses.

Outstandingly, encapsulated metsulfuron methyl 2 g a.i $ha^{-1}$ produced 689 kg $ha^{-1}$ (15.08%) more grain yield and 11.56% less weed index than the recommended dose of commercial metsulfuron methyl 4 g a.i $ha^{-1}$. These results align with the findings by Anitha *et al.* (2012) [1].

A substantial decline in grain yield (3230 kg $ha^{-1}$) and enhanced weed index (45.83%) were observed with unweeded control. The persistent and competitive nature of weeds throughout the crop growth cycle leads to reduced grain yield and elevated weed index than other methods (Manhas *et al.*, 2012) [5]. The noteworthy findings from this study indicates, each weed per square meter leads to a reduction in grain yield of 4.65 kg $ha^{-1}$ and for every gram increase in weed biomass per square meter, grain yield decreases by 18.14 kg $ha^{-1}$.

**Table 1:** Effect of metsulfuron methyl on weed density, weed dry weight, weed control efficiency, weed control index, grain yield and weed index of transplanted rice.

| Treatments | 40 DAT | | | | Grain yield (kg ha$^{-1}$) | Weed index (%) |
|---|---|---|---|---|---|---|
| | Weed density (Numbers m$^{-2}$) | Weed dry weight (g m$^{-2}$) | Weed control efficiency (%) * | Weed control index (%) * | | |
| $T_1$ | 6.46 (41.33) | 3.37 (10.99) | 92.95 | 92.70 | 5257 | 11.81 |
| $T_2$ | 4.78 (22.67) | 3.09 (9.08) | 96.14 | 93.97 | 5378 | 9.77 |
| $T_3$ | 4.18 (17.33) | 2.78 (7.23) | 97.05 | 95.20 | 5614 | 5.82 |
| $T_4$ | 4.04 (16.00) | 2.12 (3.99) | 97.27 | 97.35 | 5816 | 2.44 |
| $T_5$ | 11.44 (130.67) | 7.15 (50.70) | 77.73 | 66.33 | 3963 | 33.53 |
| $T_6$ | 10.21 (104.00) | 6.39 (40.96) | 82.27 | 72.80 | 4326 | 27.46 |
| $T_7$ | 9.86 (97.33) | 6.14 (37.54) | 83.41 | 75.07 | 4568 | 23.37 |
| $T_8$ | 9.54 (90.67) | 5.78 (32.91) | 84.55 | 78.15 | 4721 | 20.80 |
| $T_9$ | 0.71 (0.00) | 0.71 (0.00) | 100.00 | 100.00 | 5435 | 8.81 |
| $T_{10}$ | 0.71 (0.00) | 0.71 (0.00) | 100.00 | 100.00 | 5961 | 0.00 |
| $T_{11}$ | 24.22 (586.67) | 12.29 (150.57) | 0.00 | 0.00 | 3230 | 45.83 |
| SEm (±) | 0.34 | 0.22 | - | - | 274.47 | 1.69 |
| CD (5%) | 0.99 | 0.66 | - | - | 809.56 | 5.00 |

The weed density and weed dry weight data were subjected to square root ($\sqrt{X + 0.5}$) transformation before statistical analysis. The values in parentheses represent the original data.

* The weed control efficiency and weed control index data was not statistically analyzed.

$T_1$-Encapsulated metsulfuron methyl 2 g a.i ha$^{-1}$, $T_2$-Encapsulated metsulfuron methyl 3 g a.i ha$^{-1}$, $T_3$-Encapsulated metsulfuron methyl 4 g a.i ha$^{-1}$, $T_4$-Encapsulated metsulfuron methyl 5 g a.i ha$^{-1}$ $T_5$-Commercial metsulfuron methyl 2 g a.i ha$^{-1}$, $T_6$-Commercial metsulfuron methyl 3 g a.i ha$^{-1}$, $T_7$-Commercial metsulfuron methyl 4 g a.i ha$^{-1}$, $T_8$-Commercial metsulfuron methyl 5 g a.i ha$^{-1}$, $T_9$-Hand weeding on 20 and 40 DAT, $T_{10}$-Weed free check (Up to 60 DAT) and $T_{10}$-Unweeded control.

## Conclusion

The pre emergence application of metsulfuron methyl effectively controls sedges and broad leaved weeds in transplanted rice, ensuring satisfactory weed management. However, its effectiveness is significantly reduced in fields predominantly infested with grasses. Considering the ecological balance, environmental sustainability and shortage of skilled agriculture labour, this study concludes that, pre emergence application of encapsulated metsulfuron methyl at 2 g a.i ha$^{-1}$ on five days after transplanting is ideal for effective weed control, enhanced productivity and profitability of transplanted rice.

## Acknowledgement

The scholar extends heartfelt gratitude to Dr. C. R. Chinnamuthu, ICAR-Emeritus Scientist, whose unwavering support helped to shape the methodology of this research work. Equally, appreciation is extended to Professor Muthukumar Bagavathiannan, Texas A&M University, USA, whose mentorship ignited the spark of curiosity in the realm of nanotechnology. Furthermore, the scholar expresses profound thanks to the University Grants Commission (UGC), New Delhi, for their financial assistance in the form of the UGC Non-NET fellowship for the Ph.D. program.

## References

1. Anitha S, Mathew J, Abraham CT. Concurrent growing of green manure with wet seeded rice for cost-effective weed management. Indian Journal of Weed Science. 2012;44(1):34-37.
2. Gill HS, Vijayakumar. Weed index – A new method for reporting weed control trials. Indian Journal of Agronomy. 1969;14(1):96-98.
3. Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2nd ed. New York: John Wiley & Sons; c1984. p. 1-680.
4. Kaur T, Kaur S, Bhullar MS. Effectiveness of new herbicides in management of broadleaf weeds and sedges in transplanted rice. Agricultural Research Journal. 2017;54(3):329-334. DOI: 10.5958/2395-146X.2017.00061.8.
5. Manhas SS, Singh G, Singh D, Khajuria V. Effect of tank mixed herbicides on weeds and transplanted rice (*Oryza sativa* L.). Annals of Agricultural Research New Series. 2012;33:25-31.
6. Mani VS, Malla ML, Gautam KC. Weed killing chemicals in potato cultivation. Indian Farming. 1973;23(1):17-18.
7. Marimuthu S, Pavithran P, Gowtham G. Polymeric systems for the delivery of herbicides to improve weed control efficiency. In: Pesticides-updates on toxicity, efficacy and risk assessment. London: Intech Open Publishers; c2022. p. 1-34. DOI: 10.5772/intechopen.104629.
8. Maznah Z, Ismail BS, Eng OK. Residue and dissipation kinetics of metsulfuron methyl herbicide in soil: A field assessment at an oil palm plantation. Biomolecules. 2020;10(7):1067. DOI: https://doi.org/10.3390/biom10071067.
9. Mishra A, Tosh GC. Chemical weed control studies on dwarf wheat. Journal of Research (Orissa University of Agricultural Science and Technology). 1979;10:1-6.
10. Mukherjee D, Singh RP. Effect of low doses of herbicides on divergent weed flora in transplanted rice. Oryza. 2004;41(1-2):20-23.
11. Sahoo U, Malik GC, Banerjee M, Sahoo B, Maitra S. Application of nanotechnology in agriculture in India. Indian Journal of Natural Sciences. 2022;13(72):44422-44429.
12. Shivashenkaramurthy M, Roopa S, Patil MJ, Manju KS, Neeralagi KA. Effect of new generation ready mix herbicide against complex weed flora in transplanted paddy and its residual effect on succeeding black gram crop. International Journal of Current Microbiology and Applied Sciences. 2021;10(5):472-488. DOI: 10.20546/ijcmas.2021.1005.055.

13. Sumekar Y, Kurniadie D, Widayat D, Yuniarti A. Effectiveness and persistence of metsulfuron methyl herbicide in rice fields with compost organic materials. Asian Journal of Plant Sciences. 2021;20(4):609-619. DOI: 10.3923/ajps.2021.609.619.
14. Sureshkumar R, Durairaj NS, Marimuthu S, Muthukumar M. Weed characters and indices of transplanted rice as influenced by different weed management practices. International Journal of Agricultural Sciences. 2016;8(51):2221-2223.
15. Thura S. Evaluation of weed management practices in the System of Rice Intensification (SRI). M.Sc. Thesis. Department of Agronomy, Yezin Agricultural University, Myanmar; c2010.
16. USDA. The global rice production data [Internet]. United States: US Department of Agriculture; [cited 2024 Jun 17]. Available from: https://fas.usda.gov/data/production/commodity/0422110.
17. Vikram K. Season long weed management using nanoencapsulated sulfentrazone in irrigated blackgram (*Vigna mungo* L.). M.Sc. Thesis. Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore; c2020.
18. Yadav DB, Yadav A, Punia SS, Singh N, Duhan A. Pretilachlor + pyrazosulfuron-ethyl (ready-mix) against complex weed flora in transplanted rice and its residual effects. Indian Journal of Weed Science. 2018;50(3):257-261. DOI: 10.5958/0974-8164.2018.00055.2.